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Effect of Point-of-Use, Activated Carbon Filters on the Bacteriological Quality of Rural Groundwater Supplies†

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The water quality of 24 rural, domestic groundwater supplies treated with point-of-use, powdered activated carbon (PAC) filters was monitored to determine how such treatment might impact the bacteriological quality of private, residential drinking water supplies. Heterotrophic-plate-count (HPC) and total coliform analyses were performed on raw, PAC-treated, and overnight or stagnant (first-draw) PAC-treated water samples. Densities of HPC bacteria were elevated by 0.86 and 0.20 orders of magnitude for spring and well water systems, respectively, in PAC-treated effluents following overnight stagnation compared with levels in untreated effluents. Densities of HPC bacteria in PAC-treated effluents were significantly reduced ($P < 0.01$) below influent levels, however, after the point-of-use device was flushed for 2 min. While PAC significantly reduced the number of coliforms in product waters ($P < 0.01$), these indicator organisms were still detected in some effluents. Seasonal variations were evident in microbial counts from spring but not well water systems. It appears that aside from periods following stagnant-water use, such as overnight, PAC treatment does not compromise the bacteriological quality of drinking water obtained from underground sources.

The current attention focused on water quality has expanded the market for home water treatment devices. Activated carbon, in granular (GAC) or powdered (PAC) form, is commonly incorporated into filters used as home treatment devices. These devices can be fitted to service an entire home at the point of entry or at a single faucet, with the latter termed point of use (POU) devices. Carbon filters aid in the removal of organic compounds from water, but they may be less effective in removing microbial contaminants. Wallis et al. (19) warned against the incorporation of charcoal filters into domestic water systems after observing that bacterial densities were increased in treated waters following an overnight period of nonuse. In a comprehensive study of home water treatment systems, which included activated carbon units, Bell et al. (2) reported significant increases in test-unit effluent heterotrophic-plate-count (HPC) densities compared with influent HPC levels after overnight and 2-day stagnation periods. Reasoner et al. (10) found larger populations of HPC bacteria in GAC effluent water than in laboratory tap water. These investigators also suggested that high HPC densities may prevent pathogenic bacteria from colonizing and persisting on GAC filter beds.

Several controlled laboratory studies on the influence of activated carbon home filter devices on the bacteriological quality of product water have been conducted (2, 7, 10, 11, 16, 17, 19). Field studies have been of limited scope (2, 7, 16, 17), and few have included private water systems supplied from groundwater (7). Given that epidemiological data indicate that a significant number of disease outbreaks and cases in the United States have been linked to contaminated groundwater (6, 9, 14), it is likely that homeowners in rural areas may turn to POU devices to treat their groundwater drinking supplies. Thus, the current research was designed to examine the influences of POU-PAC filters on the bacteriological characteristics of private, rural, groundwater supplies in Preston County, West Virginia. These units were challenged with untreated groundwater under actual home-usage situations.

MATERIALS AND METHODS

Study area. The study area was located in a rural community of Preston County, West Virginia. Thirteen drilled wells and 11 springs, with influent water quality ranging from <1 to >100 total coliforms per 100 ml, were examined during the study. Except for one well, which had a history of nonchemical treatment (paper filter cartridge for removal of particulate matter), the water supplies had not received any water quality treatment. All 24 water systems received only the experimental treatment (PAC filtration) during the course of the study.

PAC filter installation. Water purification devices were installed in 24 private homes during January and the first week of February 1990. Six units were installed in 2-week intervals to facilitate water quality monitoring. Filter devices consisted of a RainSoft (RainSoft Water Conditioning Co., Elk Grove Village, Ill.) filter housing unit fitted with a model no. 9791 PAC filter cartridge. The units were installed by a RainSoft representative. Each filter cartridge consisted of approximately 670 cm^3 of PAC medium.

All units were connected to the cold water waterline underneath the kitchen sink via a saddle valve and a flexible waterline that permitted discharge of treated water from a separate third faucet device. In this manner, we were able to collect an influent (untreated-unfiltered) water sample from the homeowner's original kitchen sink faucet, as well as an effluent (treated-filtered) water sample that passed through the installed purification device.

Sample collection. Water samples were collected at the time of installation and approximately every 2 months thereafter for a year. Since six purification devices were installed in separate homes at 2-week intervals, six test sites were visited every 2 weeks. Every 8 weeks, a new sampling rotation was started.

On several occasions, water samples could not be collected because no individual was available to permit entry into the home. In order to minimize loss of data, each resident was mailed a water sampling schedule, which also included instructions to refrain from using his third faucet filter the night and morning before a scheduled sampling date. In addition, occupants were contacted by telephone 24 to 48 h prior to each collection date to remind them not to use their third faucet filter before sampling to ensure the availability of a "first-draw" sample.

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TABLE 1. HPC analyses of filter cartridge core samples

Filter location	HPC density (CFU/g)	
	Top[a]	Bottom[a]
Spring 4[b]	3.6×10^6	5.0×10^6
Spring 14[b]	7.3×10^5	NS[c]
Spring 17[d]	3.9×10^5	4.7×10^4
Spring 20[b]	3.5×10^5[e]	NS
Well 1[d]	7.1×10^4	6.2×10^4
Well 3[d]	2.6×10^5	2.5×10^5
Well 6[b]	8.1×10^5	1.3×10^6
Well 12[d]	6.8×10^4	3.5×10^3
Well 24[d]	6.8×10^6	6.6×10^6
Control A[f]	1.0×10^3	NS
Control B[f]	5.0×10^2	1.6×10^3

[a] Location in filter cartridges from which core samples were collected.
[b] Core sample collected after filter was replaced during course of study.
[c] Core sample not collected from this location.
[d] Core sample collected at end of study.
[e] Single core sample collected from middle of filter cartridge.
[f] Unused manufacturer's filter cartridge.

First-draw filtered samples were collected aseptically in sterile, 1.5-liter plastic bottles from the third faucet filter and constituted the first volume of water to be discharged from the purification device following an overnight, static (nonuse) period. After collection of this sample, the original sink faucet and the filter faucet were each flushed for 2 min. Any screening devices were removed from the original sink faucets. With the water still running, an unfiltered water sample was collected from the original faucet and a comparative postflush filtered water sample was obtained from the filter faucet. Each sample was collected aseptically in a separate sterile, plastic, 1-liter bottle. All sample bottles were filled approximately 80% to permit adequate headspace for mixing of the contents prior to analysis. Samples were stored in a plastic cooler packed with ice for transport to the laboratory, where they were immediately transferred to a refrigerator for storage at 4°C until the next day for processing.

Microbial enumerations. Water samples were analyzed for total coliform and HPC bacteria by the membrane filtration technique (1) by passing water through Millipore type HA 0.45-μm-pore-size membrane filters (Millipore Corp., Bedford, Mass.). Two volumes were each tested in triplicate for all samples to increase the probability of obtaining plate counts within acceptable ranges.

HPC bacteria were enumerated by using R2A medium (Difco Laboratories, Detroit, Mich.). Plates were enclosed in a plastic bag containing moist towels to prevent dessication and incubated for 7 days at 35°C (1). Coliforms were grown on M-Endo medium (BBL Microbiological Systems, Becton Dickinson and Co., Cockeysville, Md.) and incubated at 35°C for 24 h (1). Confirmation tests, using brilliant green lactose bile broth (BBL) and lauryl sulfate broth (BBL), were conducted on selected sheen and nonsheen colonies to achieve accurate coliform counts (1).

POU-PAC filter core analysis. To estimate the extent of bacterial colonization of filter cartridges, total coliform and HPC bacteria were enumerated from cored samples taken from POU-PAC filter cartridges. During the course of the study, core samples of approximately 0.7 g were taken from filters that treated three springs and one well on occasions when the filter cartridges were replaced. Five other filter cartridges, one from a spring and four from wells, were similarly examined when they were removed following completion of the study. In addition, two unused cartridges were cored to serve as controls. In the case of the control samples, the cartridges were hydrated in sterile, distilled water for 1 h prior to sampling. Two cored samples, taken approximately 5 cm from the top and bottom, respectively, from each cartridge were analyzed. Samples were removed aseptically from cartridges with a no. 6 tree borer immediately upon their return to the laboratory. The cartridges were transported on ice in sterile plastic bottles.

Bacteria were desorbed from the PAC medium according to a method developed by Camper et al. (4). A Servall omnimixer (Ivan Sorvall, Inc., Norwalk, Conn.) was used to homogenize at 16,000 rpm each sample in an ice bath. Coliform and HPC spread-plate analyses were performed on M-Endo and R2A media, respectively. Since each sample was desorbed in a 99-ml solution, effective dilution volumes of 10^{-3} through 10^{-8} were spread in triplicate for each analysis. Serial dilutions were achieved in 99 ml of 0.1% peptone buffer. Incubation times and temperatures, as well as coliform confirmatory tests, were as described previously. Bacterial counts were recorded on a per-gram-dry-weight basis. Core sample dry weights were determined after overnight baking in an oven at 80°C.

Statistical methods. Water quality data were analyzed by the analysis-of-variance statistical method with SAS computer software, version 5.18 (SAS Institute Inc., Cary, N.C.). Core data *t*-test analyses were completed with the aid of EXCEL computer software (Microsoft Corp., Redmond, Wash.).

RESULTS AND DISCUSSION

HPC densities in filtered water following overnight static periods. Microbial colonization of POU devices containing activated carbon reportedly occurs shortly after installation (10). Although we did not examine cartridge materials within a few days of installation in our study, it is apparent from our core analyses that the PAC contained high densities of HPC bacteria after several months of use (Table 1), suggesting that trapped organic materials within the activated carbon supported growth of heterotrophic bacteria. HPC densities detected in filter-treated spring waters following overnight static periods were elevated compared with densities detected in untreated spring waters (Fig. 1). First-draw filtered effluents contained HPC densities that were from 5 to 100 times greater than those found in the corresponding influent waters (Table 2). First-draw filtered HPC densities of well water systems also increased, but these were only slightly higher than their corresponding influent counts (Fig. 2).

The elevated plate counts following static periods were pre-

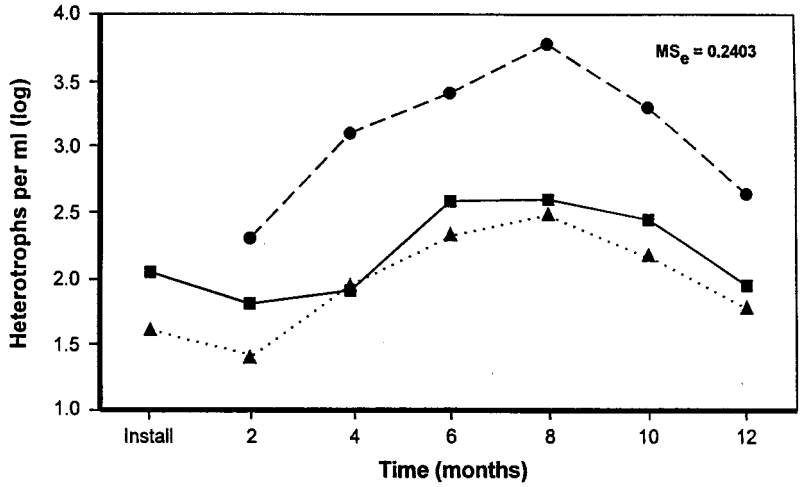

FIG. 1. Mean HPC densities of spring water systems ($n = 11$). Symbols: (■), unfiltered water samples; (●), first-draw filtered water samples; (▲), postflush filtered water samples. MS_e, mean standard error.

TABLE 2. Mean log difference between HPC bacterial populations of first-draw filtered and unfiltered water samples[a]

Water system no. and type[b]	HPC mean log difference
17s	2.01
14s	1.08
11s	1.03
16w	1.02
19s	1.02
22w	0.95
2w	0.75
7s	0.75
20s	0.70
13s	0.68
21s	0.66
10s	0.65
5w	0.63
4s	0.59
8s	0.50
15w	0.42
12w	0.33
18w	0.25
24w	0.02
23w	0.01
1w	−0.58
3w	−0.67
6w	−0.82
9w	−0.88

[a] First-draw filtered water was PAC-treated water collected after a nonusage period. Unfiltered water was nonfiltered water collected after a 2-min flushing period.

[b] Letters indicate water system type (s, spring; w, well).

dictable. Taylor et al. (16) suggested that POU carbon filters contributed to bacterial densities in product water being increased by 1 to 2 orders of magnitude over numbers detected in public water sampled at the tap. Several investigators (8, 10, 19) have reported similar findings. Only 6 of the 24 groundwater systems in the present study had increases in HPC bacteria of these magnitudes following an overnight static period (Table 2). In general, however, bacterial densities of PAC-treated spring and well water effluents were elevated compared with those of influents. These differences were generally greater in spring than in well water supplies.

Overnight, static water conditions may provide an opportunity for bacterial growth within the PAC. Of greater concern are more lengthy static conditions, such as might be encountered following vacations or other extended absences. Geldreich and Reasoner (8) found that a 6-week no-flow period increased bacterial counts 1,000- to 10,000-fold over densities associated with overnight static periods. The concern over elevated HPC arises from the possible inclusion and/or numerical increase of opportunistic pathogens, which may increase consumer exposure to health risks (17, 19). Some investigators (7, 11), however, suggest that activated carbon has no significant effect on bacterial levels in drinking water on the basis of their findings that bacterial densities were similarly increased in unfiltered water after periods of nonuse. Additionally, an epidemiological study by Calderon (3) gave little evidence to associate any health risks with the use of carbon filters.

HPC densities in filtered water after flushing. While HPC bacteria in springs and wells increased in first-draw filtered effluents compared with their respective influents, HPC levels for both decreased significantly ($P < 0.01$) in filter effluents following a 2-min flushing period (Fig. 1 and 2). Fiore and Babineau (7) also found that a 2-min flushing period reduced bacterial populations in filter effluents. Such results would seem to indicate that any potential public health concern from exposure to elevated HPC in POU filter effluents following periods of nonuse may be reduced or eliminated by flushing the POU device before use.

PAC treatment differentially affected ($P < 0.01$) these two types of water systems (Fig. 1 and Table 2). On the average, the bacterial densities in first-draw filtered samples rose nearly 0.9 and 0.2 orders of magnitude above those in unfiltered samples for springs and wells, respectively. An opposite and reverse effect was observed after the POU devices were flushed. In postflush filtered samples, bacterial levels decreased 0.2 and 0.9 orders of magnitude, respectively, for springs and wells. These differences in effluent water quality could not be attributed to differences in the numbers of heterotrophs colonizing the PAC filters treating these two types of water systems as evidenced by a group comparison t test of core sample data (Table 1). Tobin et al. (17) proposed that levels and types of organic matter in treated water could influence the severity of filter colonization. Evidence suggests that springs are more susceptible to contamination than drilled wells (12, 15), presumably because the former are shallower and more prone to

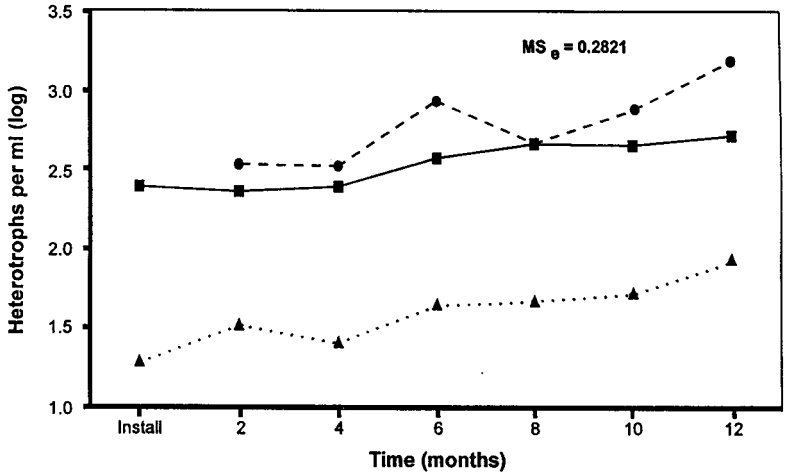

FIG. 2. Mean HPC densities of well water systems ($n = 13$). Symbols: (■), unfiltered water samples; (●), first-draw filtered water samples; (▲), postflush filtered water samples. MS_e, mean standard error.

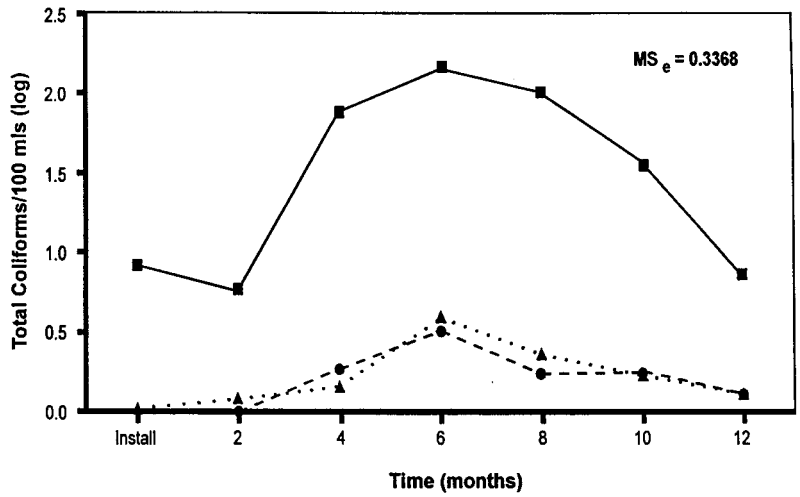

FIG. 3. Mean total coliform densities of spring water systems ($n = 11$). Symbols: (■), unfiltered water samples; (●), first-draw filtered water samples; (▲), postflush filtered water samples. MS_e, mean standard error.

surface contamination (15). Consequently, in our study, spring water samples may have had a higher organic load, which could have led to a higher concentration of adsorbed organic compounds on the surfaces of PAC filters. In turn, this could translate into more available nutrients for microbes to use for growth, especially during overnight, nonuse periods. Van der Kooij (18) reported that assimilable organic carbon levels in water were reduced 90% when water was passed through GAC filters colonized by bacteria. In the present study, the effects of water nutrient load on HPC bacteria are unknown, since organic carbon levels were not monitored.

Seasonal effects on water quality. A seasonal effect in bacterial counts for springs was observed, with densities being highest during the warm, summer months (Fig. 1). The difference in bacterial densities of unfiltered and first-draw filtered samples generally increased from colder to warmer months. Reasoner et al. (10) also noted this seasonal effect in their microbiological studies of third-faucet, POU devices. Temperature, including the ambient air temperature surrounding the POU device (8), can have a significant effect on bacterial growth on activated carbon (17). A seasonal effect was not observed for wells (Fig. 2), probably because these were drilled wells and were not subject to surface phenomena more commonly influencing water sources that exist at the ground surface, such as springs.

Coliform analysis. Use of POU-PAC filters to treat rural groundwater systems did not elevate detectable numbers of coliforms (Fig. 3 and 4), a group of organisms used to indicate the possible presence of microbial pathogens. Although coliform bacteria were detected in some effluent water samples, coliform counts from both types of filter-treated effluents were lower than levels observed in influent water, even during the summer months when coliform densities were at their highest. Several investigators have also reported that the use of activated carbon in water treatment did not elevate coliform numbers (7, 13). Camper et al. (5) reported on the ability of human pathogens, including enteropathogenic *Escherichia coli*, to colonize virgin GAC medium. The numbers of pathogens declined, however, when these filters were exposed to river water. Reasoner et al. (10) similarly suggested that high densities of

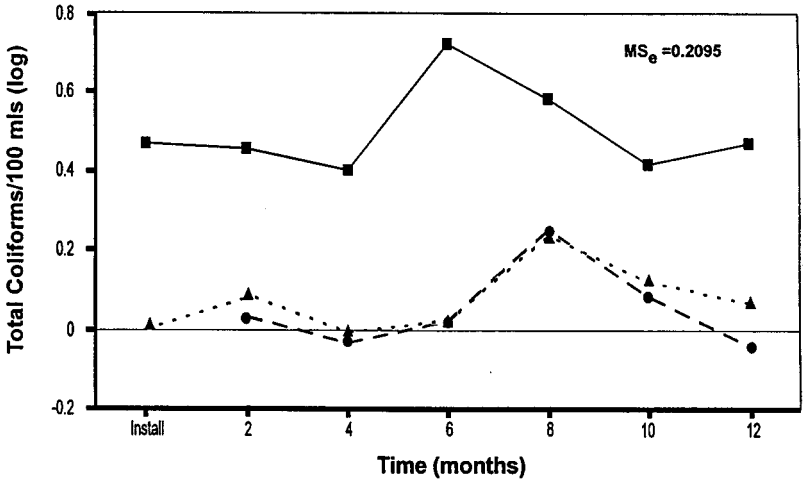

FIG. 4. Mean total coliform densities of well water systems ($n = 13$). Symbols: (■), unfiltered water samples; (●), first-draw filtered water samples; (▲), postflush filtered water samples. MS_e, mean standard error.

heterotrophs, as were observed in the present study (Fig. 1 and 2), may prevent pathogenic bacteria from colonizing and persisting on GAC filter beds.

Conclusion. One of the most important aspects of this investigation was its field orientation. Rather than home water usage being mimicked in the laboratory, POU devices were utilized by consumers under actual home-usage conditions. Additionally, these devices were challenged with domestic water supplies from groundwater sources that otherwise did not receive any type of treatment before being consumed or utilized. For these types of water systems, this research showed that while total coliform and HPC bacteria were sometimes detected in POU–PAC-treated effluents, their numbers were significantly reduced below the levels detected in untreated water, provided the tap was allowed to run for 2 min. This reduction in HPC bacteria did not occur when these devices remained static, such as overnight. Consumers who use POU-PAC treatment should flush their units following periods of nonusage.

This study does not suggest that activated carbon filters should be used in lieu of coliform testing and disinfection of drinking water where needed. Whenever potability is in question, public health guidelines should be followed. For best protection, spring and well water consumers should test their water on at least an annual basis, even after installment of any treatment device.

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